IRceL® Operating Instructions

IRceL® CO2 — Carbon dioxide sensor
IRceL® CH4 — Methane sensor

Contents

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611
www.citytech.com

Introduction

The City Technology IRceL® range of miniature infra-red 4-series gas sensors are intended for use in industrial safety and air quality monitoring applications. There are 2 sensors available:

IRceL® CO2 0-5% CO2
IRceL® CH4 0-5% vol. Methane

The IRceL® uses the Non Dispersive Infra-Red (IR) method with a novel non focusing optical design and smart technology to give high performance within the small size of the industry standard 4-series envelope. The IRceL® incorporates an integrated thermistor and an EEPROM containing factory set, sensor specific, calibration values so that high performance levels are maintained over a wide temperature range (-20ºC to +50ºC).
For certifications refer to the technical data sheet for the IRceL® model of interest.

Evaluation

To assist in your evaluation of the IRceL® we offer an evaluation kit with all the necessary equipment to begin making gas measurements. The kit includes an evaluation circuit with RS232 output, gas hood and enclosure to simulate an instrument housing and simple to use host software with data logging facility.

Performance

Figure 1 provides some performance details for the different versions of IRceL® measured with City Technology evaluation circuit 9112. Further performance data can be found on the individual technical data sheets for each IRceL® model

	IRceL® CO2	IRceL® CH4
RANGE	0-5% volume CO_2	0-5% volume CH_4
RESPONSE TIME	T_{90} < 35s	T_{90} < 35s
REPEATABILITY AT RANGE	<±0.075% CO_2	<±0.05%
REPEATABILITY AT ZERO	<±0.003% CO_2	<±0.015%
ACCURACY –20°C TO +50°C	Within ± (0.1% vol CO2 + 4% of concentration)	Within ± (0.1% vol CH4 + 4% of concentration)
LONG TERM ZERO DRIFT	<±0.008% vol. CO2 per month	<±0.05% CH4 per month
WARM UP TIME	<10s to full accuracy	<10s to full accuracy
SUPPLY VOLTAGE	3-5V DC 2Hz , 3.3V to utilise EEPROM calibration	3-5V DC 2Hz , 3.3V to utilise EEPROM calibration
POWER CONSUMPTION	<100mW mean at 3.3V	<100mW mean at 3.3V

Figure 1. Key performance measures for IRceL® sensors.

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611
www.citytech.com

Instrument Development

This section provides a guide to developing the IRceL® in to an instrument. There are some design principles which, if properly followed, will help to ensure high accuracy and long term measurement stability. The essential elements of an instrument are shown in the schematic of figure 2.

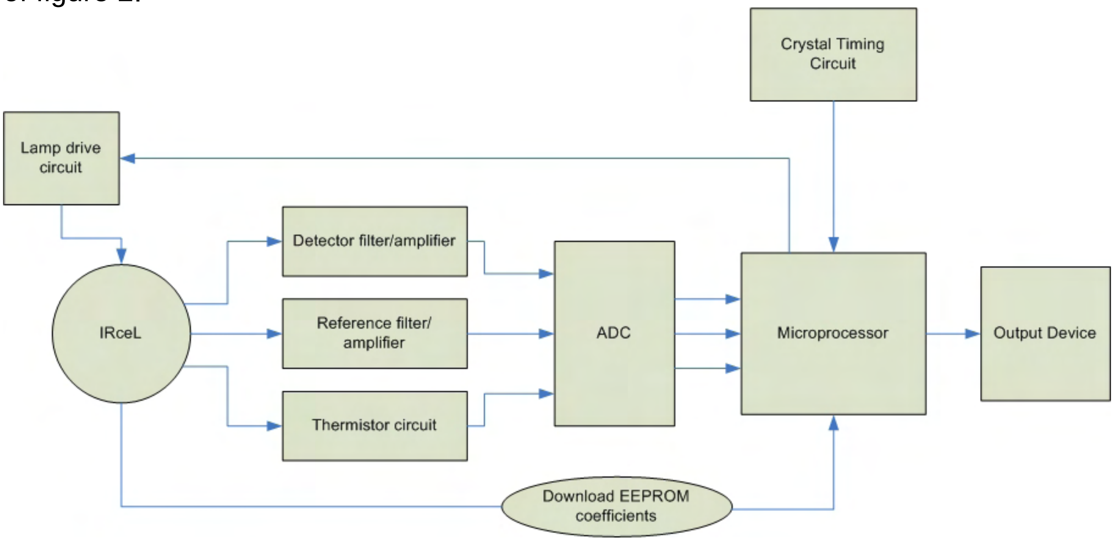

Figure 2. Schematic of an instrument utilising the IRceL®

1. Lamp drive circuit

The lamp should be connected in series with a 10Ω ballast resistor (we recommend that this resistor has a temperature dependency, TCR, of 25ppm/ºC or less) and powered with a 2Hz square wave at 3.3V. A simple method of doing this uses a MOSFET controlled by a square wave from a microprocessor as illustrated in figure 3. An external crystal timing chip is recommended to maintain long term stability of the timing. Connection to the lamp is made through pins 1 and 2 of the sensor, see figure 4 for the sensor pin arrangement. Care should be taken that the switching of the lamp does not cause the voltage supply to sag in any other part of the circuit. Independent regulation of the lamp is recommended.

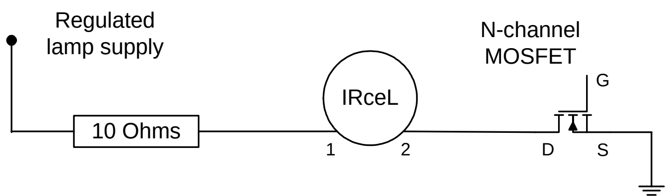

Figure 3. Lamp power supply arrangement.

www.citytech.com
City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

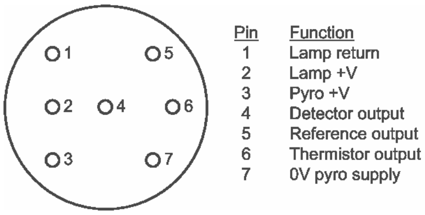

Figure 4. IRceL® pin arrangement when viewed from the bottom

2. Pyro-electric detector power supply

The pyro-electric detector is powered through pins 3 and 7 of the IRceL®, pin 3 connects to the positive supply and pin 7 connects to 0v, see figure 4. These pins are also used when communicating with the memory chip integrated in the IRceL®; this is described in detail in the following section.

3. IRceL®

The IRceL® should be connected to the circuit using PCB sockets only. Soldering to the pins can seriously damage the sensor.

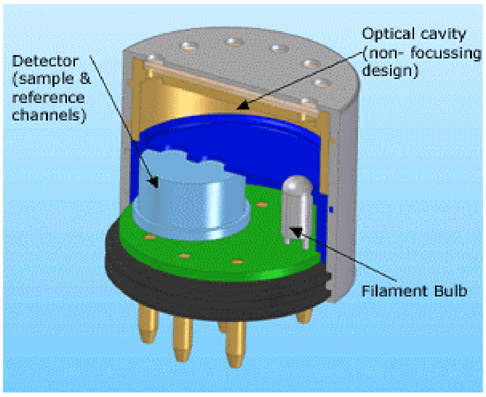

Figure 5. A cutaway model of the IRceL® showing the key components

The IRceL® is a miniature infra-red gas sensor module using the tried and trusted NDIR technique along with smart calibration technology to achieve excellent performance.

Gas diffuses in to the IRceL® through holes in the top of the stainless steel casing passing through a particulate and flame arresting gauze. The infra-red source used in the IRceL® is a tungsten filament bulb conditioned for low drift of emitted IR flux. Light from the bulb makes numerous passes of the gold plated optical chamber passing through the gas sample under measurement.

IR detection is achieved using a dual channel temperature compensated pyroelectric detector, the optical aperture of each channel being covered by optical band-pass filters. The 'GAS' channel uses an optical filter centred around an IR wavelength attenuated by the target gas. It is this attenuation of light in the GAS channel that allows us to calculate the gas

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611
www.citytech.com

concentration. The 'REFERENCE' channel uses an optical filter centred on an IR wavelength where the atmospheric and target gases do not cause light attenuation. Referencing provides an increase in the stability of gas detection helping to minimise long term drift and potential errors such as intensity changes in the light source or reflectivity change of the optical cavity due to pollutant aggregation. The pyroelectric detectors measure the light transmitted through the gas on each channel and respond to the *change* in thermal IR flux incident on them, it is for this reason that the IRceL® lamp is pulsed and a low frequency AC measurement scheme is used. The response of the pyroelectric detectors is highly dependent upon the ambient temperature so a thermistor is thermally bonded to the pyroelectric detector housing, enabling accurate compensation for this effect. Each IRceL® contains an integrated memory chip that holds sensor specific calibration factors. This means that excellent temperature performance will be achieved without the need for any time consuming temperature characterisation in the host instrument, overcoming a traditional drawback of this sensor type.

The EEPROM used in the IRceL® CO2 and IRceL® CH4 is the DS2431 from Dallas Semiconductor. There are 512 bits of factory set memory and 512 EEPROM bits accessible to the host instrument.

Memory map (DS2431)

ADDRESS	DATA TYPE	DATA SIZE	DATA NAME	DESCRIPTION		Row	Page
0	unsigned int	1	ST	Sensor Type	THIS SECTION IS LOCKED FOR EDITING	0	Zero
1	unsigned int	4	SN	Serial Number			
5		3		Reserved			
8	float	4	FZCC	Factory Setting		1	
12	float	4	QZ	Zero Quadratic Temperature Coefficient			
16	float	4	LZ	Zero Linear Temperature Coefficient		2	
20	float	4	CZ	Zero Constant Temperature Coefficient			
24	float	4	h	linearization coefficient h		3	
28	float	4	i	linearization coefficient i			
32	float	4	j	linearization coefficient j		4	One
36	float	4	k	linearization coefficient k			
40	float	4	m	linearization coefficient m		5	
44	float	4	n	linearization coefficient n			
48	float	4	p	linearization coefficient p		6	
52		4		Atmospheric pressure at calibration (mBar)			
56		4		Reserved		7	
60		4		Reserved			
64	float	4	ZCC	Gas Zero Constant		8	Two
68	float	4	SM	Span Multiplier			
72	unsigned int	2	LA	Low Alarm Set Point		9	
74	unsigned int	2	HA	High Alarm Set Point			
76	unsigned int	2	AS	Analog Output Span			
78		2		Not Used			
80		8		Not Used		10	
88		8		Not Used		11	
96		8		Not Used		12	Three
104		8		Not Used		13	
112		8		Not Used		14	
120		8		Not Used		15	
128		8		Protection Control Bytes			

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

The sensor types are:

ADRESS 0 BYTE	SENSOR TYPE
6	IRceL® CH_4
7	IRceL® CO_2

Accessing the EEPROM

The EEPROM is connected between pins 3 and 7 of the IRceL® which are also used to supply power to the pyroelectric detector. The intended method for accessing the EEPROM is using the 1-wire protocol developed by Dallas Semiconductor using DATA and GND connections. This has to be carried out when no measurements are being taken from the detector so it is recommended that on start up the EEPROM is interrogated and its contents downloaded.

Further details of the DS2431 EEPROM and Dallas Semiconductor 1-wire protocol can be found from the Dallas Semiconductor website: www.maxim-ic.com or from your technical support advisor at City Technology.

4. Filter/Amplifier circuits

The output from the sensor on both the GAS and REFERENCE detector channels are analogue voltages typically <30mV modulated in sympathy with the lamp modulation frequency and superimposed on a DC voltage. The amplitudes of modulation must be measured to enable calculation of the target gas concentration. The signals require filtering and amplification before they can be sampled by an ADC. A suggested circuit for this is shown in figure 6. To maintain long term stability of the gain of these circuits, and hence stability of the gas measurements, the capacitors and resistors used should have low drift with time. Whilst most component manufacturers do not specify this, drift for these components scales approximately with the components temperature induced change in value. We recommend that capacitors are PPS and have a temperature dependency, TCR, of 100ppm/ºC except C1 where an electrolytic can be used. We recommend that all resistors have a temperature dependency, TCR, of 25ppm/ºC or less. The op-amp used in this circuit is the OPA2364 from Texas Instruments which has a maximum voltage output swing from rail of 20mV. Using the recommended circuit and power supply with this op amp ensures that the output waveform from the IRceL is not limited by the rail when amplified.

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

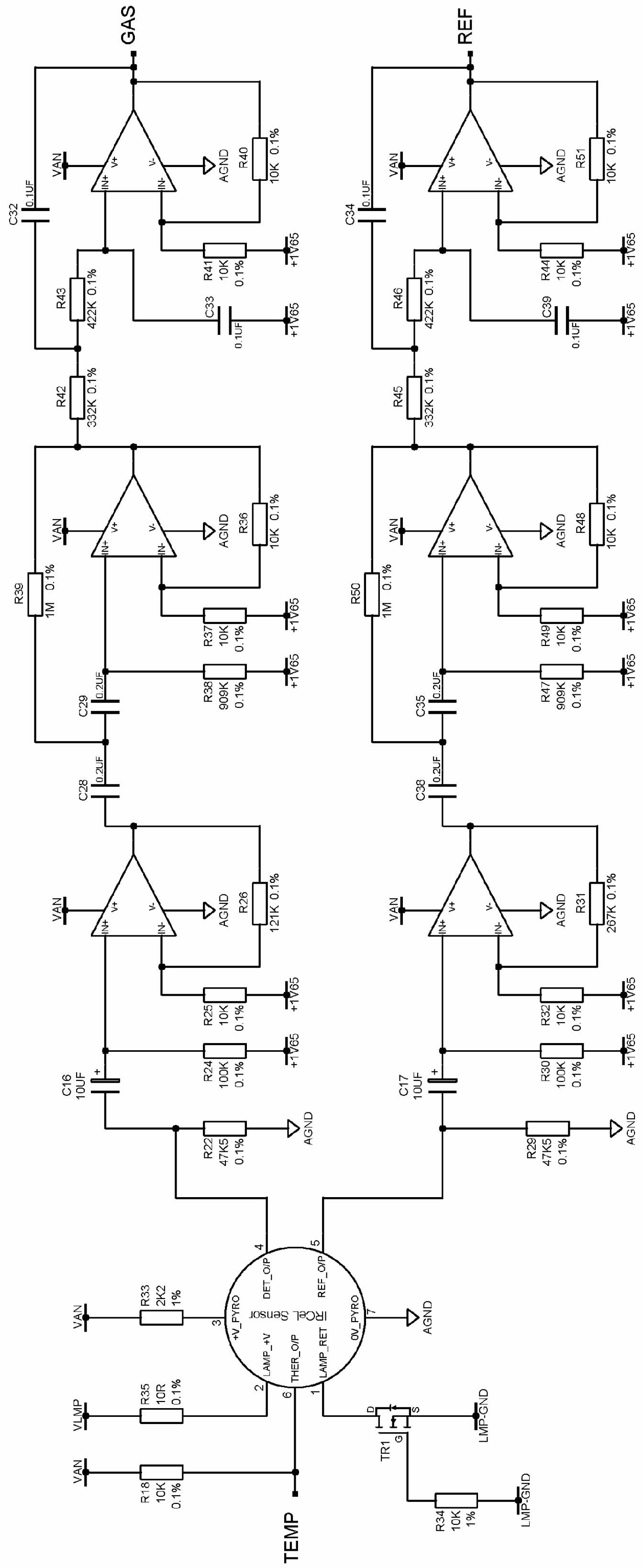

Figure 6. Analogue filter/amplifier circuit schematic

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

5. Thermistor circuit

The Pyroelectic detector sensitivity has a significant temperature dependency. A thermistor is contained in the sensor housing to enable compensation for this and retain gas measurement accuracy over the operating temperature range of –20ºC to +50ºC. One end of the thermistor is connected to pin 6 whilst the other end is earthed. The thermistor resistance is found by making a potential divider between it and a second known value of resistance (we recommend that this resistor has a temperature dependency, TCR, of 25ppm/ºC or less). Use the ADC to monitor the potential at the junction and hence determine the temperature according to the following table:

Thermistor resistance at 25ºC = 3,000 Ohms ± 1%

Temp (ºC)	Resistance (Ohms)
-30	69,710
-20	35,550
-10	19,080
0	10,710
10	6,269
20	3,803
25	3,000
30	2,386
40	1,546
50	1,031
60	707

Note that the factory calibration equipment determines the temperature by making a straight line fit between adjacent data points to determine the temperature.

The temperature measured inside the IRceL is on average 2°C hotter than the surrounding temperature due to the heat of the bulb, this has the additional advantage of protecting the optics from condensation.

6. Analogue to Digital Converter

A 12 bit or higher ADC is recommended to achieve a high resolution in gas measurement. The output from the two filter/amplifier circuits and the thermistor circuit should be sampled against a stable voltage reference. Sampling the filter/amplifier circuits at a high rate and summing over a complete on/off cycle of the lamp, then performing a running average of this over a number of lamp cycles will give a very accurate proportional measure of the peak to peak voltage modulation of the pyroelectric detector outputs.

7. Processor

The processor is required to control the timing of the lamp drive, receive the raw data from the ADC, download EEPROM coefficients, calculate the target gas concentration and to communicate with chosen output devices. The processor is not required to perform any sophisticated digital signal processing.

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

Calculating gas concentration

To obtain a gas measurement the instrument is required to make a calculation based upon the output values recorded from the ADC; the GAS channel raw data, the REF channel raw data and the temperature. The GAS raw data is simply the peak to peak amplitude of the sinusoidal output from the gas channel filter/amplifier and the REF raw data is the peak to peak amplitude of the output from the reference channel filter/amplifier. As described in section 6, good measurement accuracy of the GAS and REF values is achieved as the result of integrating many samples over a complete lamp cycle; you may also wish to average this over a number of successive lamp cycles. The GAS and REF values should be calculated with at least 5 significant figures. Once these values have been acquired a gas calculation can be made by following the steps in figure 7. All the constants referred to in figure 7 can be found recorded on the IRceL® EEPROM in the locations described in section 3 above.

Calibration voltage

The calibration factors programmed in to the EEPROM of each sensor are generated with the sensor operated at the voltages in the table below.

SENSOR TYPE	CALIBRATION VOLTAGE	
	V_{LAMP}	V_{PYRO}
IRceL® CH4	3.3v	3.3v
IRceL® CO2R	3.3v	3.3v

Operating the sensor at a voltage other than that at which it was calibrated will reduce the sensor performance unless the calibration factors are recalculated based upon a temperature and gas exposure routine with the sensor operated at the required voltages. If it is desirable to operate at a voltage other than the calibration voltage your technical support advisor at City Technology will be able to advise you in the design of your calibration routine.

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

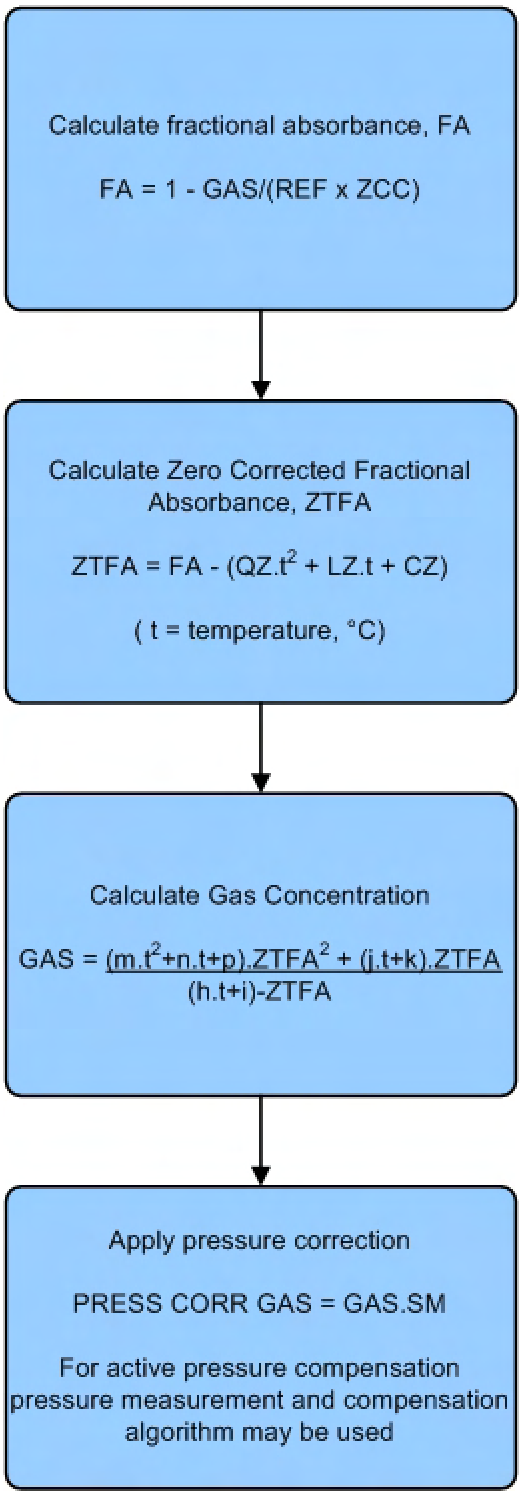

Figure 7. Gas calculation procedure. Refer to EEPROM memory maps for definitions of constants and their memory locations.

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

Zeroing operation

When the IRceL® is installed or reinstalled in an instrument, the instrument must be zeroed. First allow the instrument to warm up for 10 minutes in the presence of zero gas, e.g. 100% N_2. For a further minute measure the GAS and REF raw data and the temperature from the integrated thermistor

Using the average values of GAS, REF and temperature (in degrees C) that have been measured, recalculate ZCC and update this on the EEPROM. To calculate ZCC use:

Equation 1.
$$ZCCnew = \frac{GAS}{REF \times \left(1 - QZ \times t^2 - LZ \times t - CZ\right)}$$

Span operation

When the IRceL® is installed or reinstalled in an instrument, the instrument must be spanned. After properly zeroing the instrument expose the instrument to a span gas for 10 minutes. To obtain the best accuracy, the span procedure should be performed near the concentration that is most critical in an application or between 70% and 80% of the full-scale concentration.

Set the value of the span multiplier, SM according to:

Equation 2.
$$SM = \frac{\text{Desired value of GAS CONC.}}{\text{GAS CONC.}}$$

And GAS CONC is now calculated using

Equation 3.
$$GAS\ CONC = \left(\frac{\left(m.t^2 + n.t + p\right) \times ZTFA^2 + \left(j.t + k\right) \times ZTFA}{\left(h.t + i\right) - ZTFA}\right) \times SM$$

Spanning the sensor is a useful way to accommodate permanent pressure offsets particularly due to use at altitude.

Pressure compensation

The pressure dependency of the IRceL is non linear and dependent on gas concentration though highly repeatable from device to device. Typically at full range a 1% change in pressure will give a 1.4% in sensor reading. An example compensation algorithm for CO2 in the 0 to 5000ppm range from 700mBar to 1300mBar is given in figure 8. Further information is available from your technical support advisor at City Technology if required.

www.citytech.com
City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

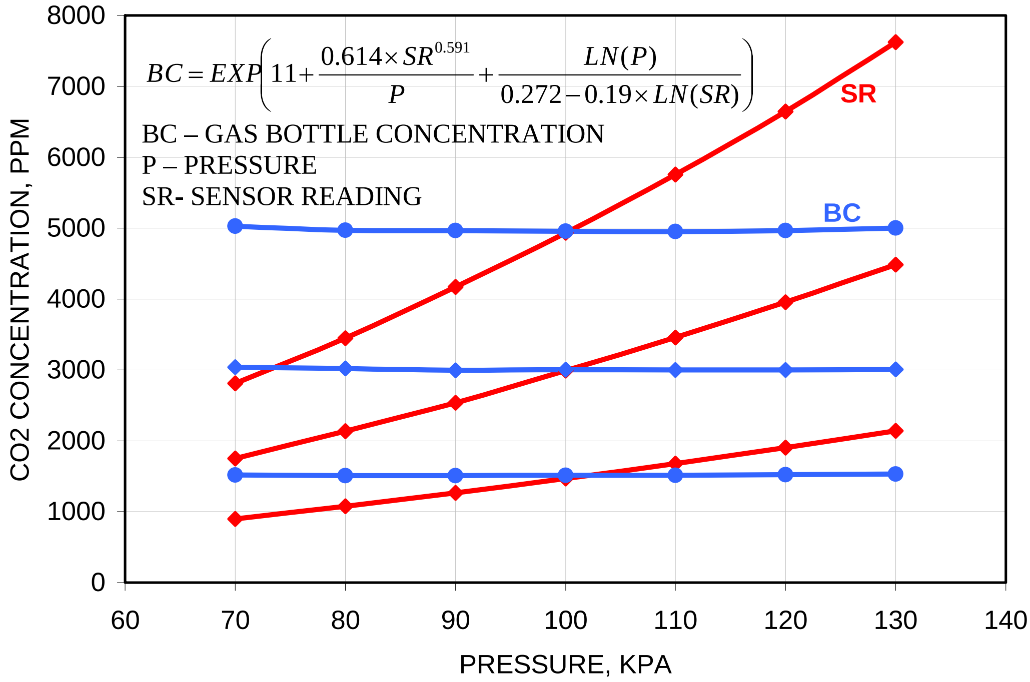

Figure 8. Pressure dependency and a compensation method for the CO2 IRceL®.

Potential error modes

While every precaution is taken to ensure that every sensor performs safely and accurately throughout its working lifetime there are still some potential causes of measurement error that include but are not limited to:

FAULT CAUSE	EFFECT
Obscuring particles entering optical chamber	Gradual reduction in both GAS and REF raw data over period of particulate deposition on optical components causing drift in the measured gas reading
Condensation forming in optical chamber	Unpredictable effect on GAS and REF raw data and measured gas reading
Condensation forming on circuit boards	Unpredictable effect on GAS and REF raw data and measured gas reading.
Prolonged exposure of circuits to high humidity	Gradual changes in both GAS and REF raw data over period causing drift in the measured gas reading

In assessing the risk of condensation in your application note that due to the filament bulb the temperature inside the optical chamber is typically 2ºC above ambient during continuous sensor operation.
Users of the sensor should be aware that the nonlinear nature of NDIR devices means that any baseline drift of the sensor causes a larger drift at span gas concentrations.

www.citytech.com
City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

Appendix A – Component choice; cost versus performance

Throughout this document we advocate using the best components in specific areas of the IRceL host circuitry to achieve the highest performing end result. The sensor specifications are written based upon its performance when used in conjunction with such circuitry. In this appendix we qualitatively discuss the effects of using cheaper components on the device performance and in which circumstances it makes sense to do so.

The area of most stringent component specification is in the filter/amplifier circuitry, specifications can be seen on P6. The high specification serves two purposes; it maintains the circuit gain to a very high accuracy over the lifetime of the device helping to minimise drift in the gas measurement and it minimises the temperature dependence of the circuit gain so that the temperature coefficients stored on the EEPROM for the sensor can be accurately used to calibrate the instrument. The component quality can be downgraded if poorer performance is adequate at the extremes of the operating temperature range or if temperature compensation is to be recharacterised based on the 'sensor in instrument' performance. The possibility of using cheaper components is much greater if using the IRceL's over certain restricted concentration ranges where the fractional absorbance gradient with respect to gas concentration is sufficiently large. Drift of the amplifier gain with time will eventually limit consideration of the very cheapest components dependent on the requirements of your application. As a cautionary note designers should consider that component drift is usually accelerated by fluctuations in temperature.

In other areas the choice of high specification components is driven by the same factors, that the manufacturers temperature coefficients for the sensor can reliably be used once it is integrated in to the instrument, and to help minimise drift in the gas measurement with time.

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611

Appendix B – RF interference and EMC

An instrument using the IRceL could be susceptible to EMI if proper precautions are not taken. The instrument manufacturer will have an idea for their intended application what EM field strength and frequencies they must safeguard against interference from. The output signals from the IRceL are in the region of 30mV and EMI induced signals on these outputs of several uV could begin to introduce small measurement errors though high frequencies will be filtered by the instruments analogue filter+amplifier circuit. The greatest opportunity for EMI pick up is in the instrument PCB track that takes the sensor output to the first stage of amplification. Interference inside the sensor body is possible, the steel casing of the sensor is isolated from any of its electrical connections and EMI could be absorbed and reradiated by the casing affecting the internal active components. An additional precaution to protect against this can be to connect the sensor body to ground. At the base of the sensor there is no covering by the outer casing only the potting resin retaining the PCB, a ground plane in the instrument circuit directly beneath the sensor would be the best protection from EMI incident from this direction.

An additional concern is with electromagnetic signals generated from components inside the instrument that might interfere with the sensor. Because of the possibility of common frequency ‘in phase’ signals (or their harmonics) that can be present this could cause problems if the circuit is badly designed (eg with an oscillator circuit or signal line running very close to the sensor output tracks). Again the precaution of a ground plane directly beneath the sensor should prevent any problems.

No measure of the susceptibility of the sensor to RFI or EMC is given because the susceptibility of the instrument to these factors largely relies upon the design of the instrument rather than the design of the sensor.

City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611
www.citytech.com

Revision History

Issue Level	Page	Revision
3	15	Revision history added
	11	Equation numbers added
	11	Correction made to equation 3
4	13	Added text “specifications can be seen on P6”
	14	Added appendix “RF interference and EMC”

www.citytech.com
City Technology Limited
City Technology Centre, Walton Road, Portsmouth, Hampshire PO6 1SZ UK
Tel +44 23 9232 5511 Fax +44 23 9238 6611